International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 8 Issue 05 Series. I || May 2019 || PP 75-80

Effect of thermoelectric subcooling on performance of vapour compression refrigeration with reduction in temperature of variable quantities of water (pull down test).

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Abstract : *The main objective of this paper is to experimentally study the variation in performance parameters of the vapor compression refrigeration system when refrigerant is sub cooled by thermoelectric peltier cooling module. Experiments are carried out on the freezer section of vapor compression refrigeration system by varying the load i.e. water quantity in Kilograms and performance is evaluated to reduce the temperature of water by* 10^0c *& parameters are measured & compared for with and without subcooling of the refrigerant. Coefficient of performance, power consumption is determined for different loads on evaporator by calculating heat loss from surrounding only by conduction to evaporator. The effect of subcooling of refrigerant by Peltier cooling is also studied to optimize the use of subcooling for the refrigeration system. The experimental study helps us to know the behavior of the VCR system for different loading conditions. A comparative study data is also carried out for with sub cooling and without sub cooling condition. Comparing the results obtained there is decrease in Power Consumption when TEC is integrated with the VCR system. For 18Kg load on evaporator there is maximum reduction in power consumption is 20.40% for with subcooling condition. For 18Kg load on evaporator there is maximum increase in actual COP is 17.21854% for with subcooling.*

Keywords – *Coefficient of performance, fixed conductance heat pipe, subcooling, thermoelectric cooling module, and figure of merit.*

Date of Submission: 01-05-2019 Date of acceptance: 13-05-2019

I. INTRODUCTION

Thermoelectric cooling is a emerging cooling technology with many players in the research & development. This technology is commercially developed & successful in producing advanced thermoelectric materials with higher figure of merit. Even though this technology can be effectively utilized for cooling purposes it cannot replace VCR system (Vapour Compression Refrigeration system) completely.VCR system almost consumes 78 percent of total market of refrigeration in the world. Due to increasing cost of electricity, it is required to optimize the performance of VCR system & it can be done by using thermoelectric cooling system to subcool the refrigerant. A standard VCR system is utilized with 1/3rdHP compressor and TEC module along with fixed conductance heat pipe is used on hot side for heat dissipation.

Subcooling after condenser increases the refrigerating effect. Pottker and Hrnjak [1] investigated experimentally that the system COP can be increased up to 9% by subcooling R134a after condenser because the state of the refrigerant entering the expansion device of conventional vapor compression cycles is usually assumed to be saturated liquid. However, liquid cooling below saturation reduces the throttling losses and potentially increases COP. Actual COP of refrigeration system is governed by corresponding refrigerating effect produced in the evaporator for the given compressor work. Riffat Xiaoli Ma [2] illustrated the cooling potential of Thermoelectric cooling technology as they are solid state cooling devices. Vián & Astrain [3] in their paper proposed a hybrid system by combining VCR & thermoelectric cooling technology. Radermacher [4] et.al proposed in his work that sub cooling can be achieved by an auxiliary thermoelectric cooling system. Therefore these thermoelectric cooling modules are used to subcool the refrigerant after condenser ultimately improving the actual COP. Heat pipe technology is effective for heat dissipation from hot side of TEC cooling module as performance of TEC module is directly proportional to rate of heat dissipation. Z. Djafar et.al. [5] in his paper illustrated that if the commercial heat pipe is mounted on the hot side of thermoelectric module to release more heat & maintain the temperature on the surface it improves performance of TEC module. Aluminium fins were attached horizontally on the condensation side of the heat pipe, and then a small fan was mounted directly on the fins to provide forced air convection to the hot side heat sink of the heat pipe.

In this paper, performance of refrigeration system is studied experimentally in terms of theoretical & actual COP and power consumed by the compressor when load on the evaporator is varied for three different quantities of water used 15kg, 16kg, 17kg.etc in evaporator with basic heat losses by conduction to the evaporator. For two conditions with sub cooling & without sub cooling the experiment is repeated for reduction of temperature from 25.7^0c to 15.7^0c of water. A percentage change in actual COP, theoretical COP and Percentage change in power consumption is determined. Finally, the effect of subcooling on the performance of an actual vapour compression refrigeration system will experimentally be investigated for refrigerant R134a under the same.

II. EXPERIMENTAL SETUP

The experimental setup consists of vapor compression refrigeration test rig consisting of evaporator (freezer section), hermetically sealed reciprocating compressor, air cooled condenser, capillary tube interconnected by copper pipe. Six suitable thermocouple & two pressure gauges with one rotameter to measure the system temperature & pressure are provided. One energy meter is provided to measure energy supplied to compressor. Suitable h.p/.l.p. cutout, thermostat, voltmeter and ammeter are also provided. Refrigerant R-134a is sub cooled by using single thermoelectric cooling pellet assembled with heat pipe and fan to dissipate heat.TEC1-12704 is used. In the specification of TEC 1 represent the single module, 127 represent the number of P-N couples and 4 represent maximum current i.e.4AMP. TEC cooling module is sandwiched between mounting block and heat pipe. Mounting block is split type which holds the refrigerant pipe. A 12V dc power supply is given to TEC cooling module which pumps the electrons between semiconductors. The extra electrons in the n-type and the holes in p-type materials works as carriers and are responsible for moving heat from cold end to hot end. The amount of heat that is absorbed at the cold junction and transferred to the hot junction is directly proportional to the carrier current that is passed through the circuit. The proper fixed conductance heat pipe with fan is attached to hot side of the TEC module for heat dissipation.

A **B**

Fig No 1 A. Experimental Setup, B TEC Module with Heat Pipe

2.1 Specifications of the system.

Vapour compression system with TEC cooling module is used for experimentation and specification of these two systems are as follows. Hermitically sealed compressor with 1/3Hp capacity is used . Condenser, capillary and condenser fan is selected for above mentioned compressor specifications.

2.1.1. Vapour compression refrigeration system:

Sr.No	Equipment	Type	Particular
1	Compressor with acc.	Hermitically sealed	KCE 419 Emerson make
2	Refrigerant	R-134A	R-134A
3	Condenser	Forced convection type	10*11*2 row
4	Fan	Condenser fan	Rexonord-9"
5	Drier/filter	Molecular sieve type liquid line filter-drier	Dry all make 1/4"
6	Glass tube rotameter	Refrigerant flow measurement	Cvg techno crafts make 0-10 lph
7	Expansion device	Capillary tube	0.036" x 7.5 ft
8	Calorimeter tank	Ss tank	25 lit.
9	Calorimeter insulation	Nitrile foam black	12mm
10	Evaporator	Direct expansion shell and coil type: refrigerant through pipe, water around coil	copper tube 3/8" od 36ft

11	Pump	Pump	Stirrer motor 40watt
12	Heater	Electric heater	1000 watts
13	Temp. Indicator	For refrigerant temperatures	Es point, 6 channel
14	Thermostat	Calorimeter temp.water temp	Subzero 7081 with pt-100 sensor
15	Heater controller	For heating control	Rheostat
16	Cooling thermostat	For cooling control	
17	Pressure Gauges (Psi)	Suction and Discharge Pressure	Wika make 0-230 1NO, 0-300 1 NO
18	Hp/lp cut out	High /low pressure cut-out	Saginomiya- 1no
19	Energy meter	For compressor & heater	L & t make, 1 #
20	Indicating lamps		Teknik, 2 nos

2.1.2. Specifications of TEC module:

Sr No	T_h	27	50
1	DT_{max}	68	76
2	U_{max}	15.2	17.2
3	I_{max}	5.2	5.2
4	QC_{max}	50.8	55.7
5	AC (Resistance)(Ohms)	2.3 to 2.7	2.54 to 2.58
6	Heat Pipe	Fixe Conductance Heat Pipe	
7	Fan	90*90*25 mm	

Mounting block is aluminum block having thickness 1.5mm and having slotted at the center having diameter equal to the diameter of the condenser pipe it will grip the condenser pipe. Mounting block is having two halves which can be tightened with the help of screws around the condenser pipe. Cold side TEC module is pasted to the plain surface of the mounting block. As temperature of mounting block reduces it will extract heat from flowing refrigerant. Temperatures before & after TEC cooling module are recorded. On hot side of the TEC module heat pipe is pasted with thermal paste. FCHP transfers generated heat at hot side by using boiling & condensation of the working substance water inside the copper tube. A very high rate of heat dissipation is obtained by using heat pipe compared to the heat sink on hot side.

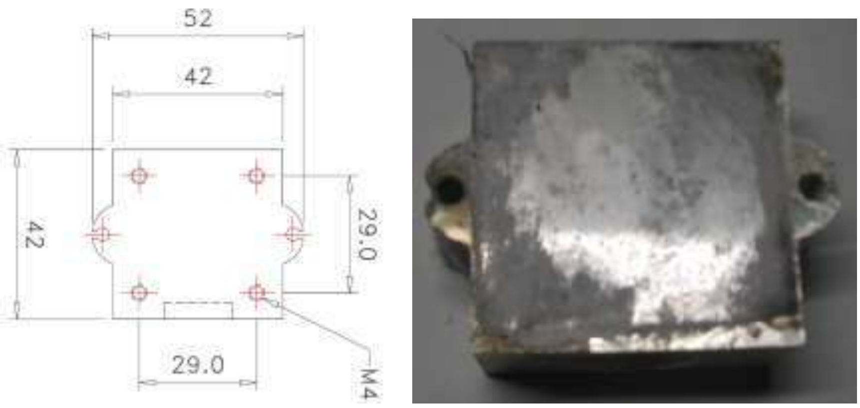


Fig No 2 Split mounting block

Fan TEC module, Heat pipe, Mounting block & fan are assembled. The mounting block holds refrigerant pipe. As cold side of TEC module cools the mounting block subsequently mounting block cools the refrigerant to obtain subcooling.

III. Experimental Procedure

The test is carried out on the VCR system to reduce the temperature of water placed in the evaporator section. Machine is placed in the proper position where its level is horizontal with good ventilation. The machine must have at least 1.0 meter clearances from all sides. Give 230 volts, 50Hz, and 1 phase supply to the unit. The electrical point should have provided with a MCB of 16 Amps rating. After ensuring proper earthing. The evaporator is filled definite quantity of water which is the load on the system. A pump with 40watts is provided in the evaporator for equalization of the temperature in the tank. Refrigerant will lose its enthalpy to water and it will evaporate. Water temperature should be reduced to 25.7^0c from this temperature the test is carried out to reduce it to 15.7^0c a 10^0c temperature difference. This simple reduction in temperature test for specified quantity of the load is conducted for two different configurations 1.With subcooling 2. Without subcooling Time is recorded for 10 pulses of compressor energy meters. High pressure and low pressure along with respective temperature values are recorded for each single degree of reduction of the temperature. This test is repeated for two configurations with & without subcooling. Power consumption, coefficient of performance is calculated considering the losses only by direct conduction in the evaporator section. A comparative chart is prepared to check % variation in Power consumption, coefficient of performance with subcooling & without subcooling.

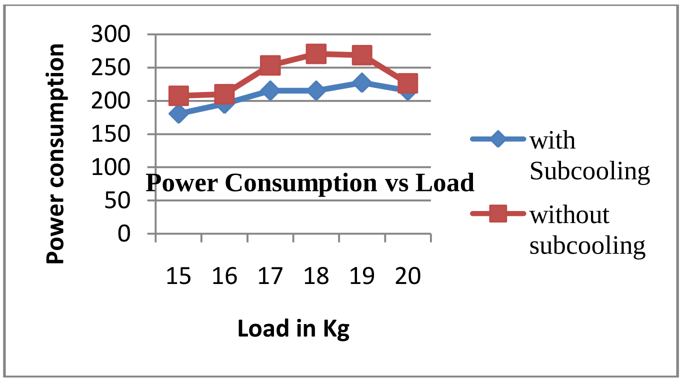
IV. Result & Discussion

The performance parameters of the system are percentage change in actual COP, theoretical COP & percentage reduction in power consumed. These variations are measured for with and without subcooling of refrigerant by thermoelectric cooling module. The performance calculations for tests without subcooling and with subcooling are as shown below. The performance of VCR system depends upon two pressures in between it works. Comparative study of experiments with two different conditions is done and the graphs are prepared for with & without subcooling. For percentage change in power consumption for different water quantities as the load on the evaporator increases power consumption also increases along with pressure variation.

4.1 Percentage change in power consumption.

In this section power consumed is analyzed for both cases with and without subcooling for five different loads on evaporators. The graph is plotted between Power Consumed Vs Load & percentage change is compared. for subcooling conditions required refrigerating effect is achieved earlier than without subcooling of refrigerant and it helps to reduce power consumption by compressor.

Sr.No	Load Kg water	Power Consumption Without TEC Kw	Power consumption with TEC Kw	% Reduction
1	15	207.5877	180.65	12.97654
2	16	209.91	195.40	6.912486
3	17	253.12	215.10	15.02054
4	18	270.25	215.10	20.40703
5	19	268.45	227	15.44049
6	20	226.29	215.107	4.941889

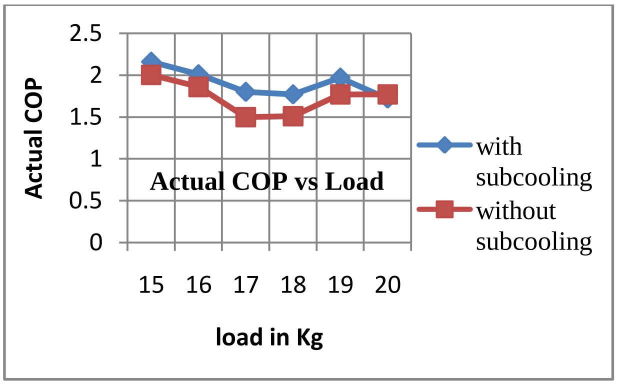


From the graph it is observed that when load on the evaporator is varied there is reduction in power consumed when TEC is integrated with VCR system for subcooling of refrigerant. for 18Kg load on evaporator there is maximum reduction in power consumption is 20.40%.

4.2 Percentage change in actual COP:

In following section actual COP is calculated and compared for both cases and graph is plotted between Load Vs Actual COP. The heat loss by conduction is added to the refrigerating load on the evaporator for ambient temperature along with load of stirrer motor 40 watts for uniform distribution of the temperature.

Sr. No.	Load Kg water	Actual COP Without TEC	Actual COP With TEC	% increase
1	15	2.0023	2.16	7.875943
2	16	1.86	2.01	8.064516
3	17	1.50	1.69	12.66
4	18	1.51	1.77	17.21854
5	19	1.77	1.97	11.29944
6	20	1.77	1.72	4.278075

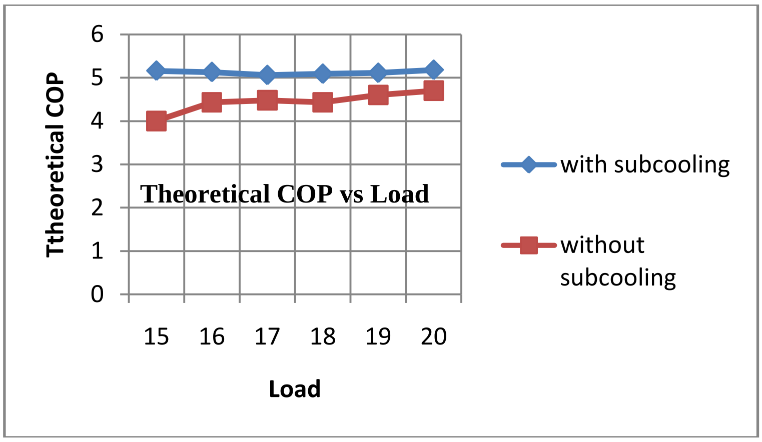


From the graph it is observed that when load on the evaporator is varied there is increase in actual COP when TEC is integrated with VCR system for subcooling of refrigerant. For 18Kg load on evaporator there is maximum increase in actual COP is 17.21854%.

4.2 Percentage change in theoretical COP:

In following section actual COP is calculated and compared for both cases and graph is plotted between load Vs theoretical COP. The P-H diagram is plotted for each combination of L.P & H.P. COP is calculated.

Sr.No	Load Kg water	Theoretical COP Without TEC	Theoretical COP With TEC	% increase
1	15	4	5.16	15.95506
2	16	4.43	5.13	15.80135
3	17	4.48	5.06	12.94643
4	18	4.43	5.09	14.89842
5	19	4.60	5.11	11.08696
6	20	4.70	5.18	10.21277



From the graph it is observed that when load on the evaporator is varied there is increase in theoretical COP when TEC is integrated with VCR system for subcooling of refrigerant. For 15Kg load on evaporator there is maximum increase in actual COP 15.95%.

V. CONCLUSION

Experimental investigation of vapor compression refrigeration system with thermoelectric subcooling by TEC module along with fixed conductance heat pipe (FCHP) for heat dissipation on hot side performance parameters are measured & conclusions are drawn that the actual COP of refrigeration system increases when refrigerant is sub cooled after condensation by using thermoelectric cooling device. The maximum increase in actual COP is 20% for load 17kg of water in the evaporator when refrigerant is sub cooled. The actual COP decrease with increase in Load on the evaporator in both cases with subcooling & without subcooling. The highest percentage reduction in power consumption by compressor is 20.40703% when refrigerant is sub cooled after condenser. Theoretical COP is also increases when refrigerant is sub cooled over without subcooling condition.

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Abhijeet Ghutepatil" Effect of thermoelectric subcooling on performance of vapour compression refrigeration with reduction in temperature of variable quantities of water (pull down test)." International Journal of Engineering Science Invention (IJESI), Vol. 08, No. 05, 2019, PP 75-80